NASA

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Information Summaries

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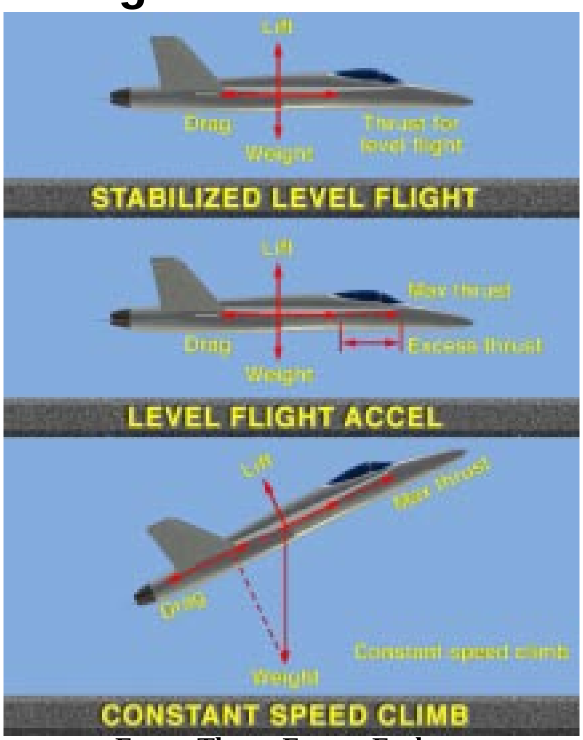
Acceleration - Deceleration

Background



Excess Thrust Energy Exchange

An aircraft in flight retains energy in two forms; kinetic energy and potential energy. Kinetic energy is related to the speed of the airplane, while potential energy is related to the altitude above the ground. The two types of energy can be exchanged with one another. For example when a ball is thrown vertically into the air, it exchanges the kinetic energy (velocity imparted by the thrower), for potential energy as the ball reaches zero speed at peak altitude.

When an airplane is in stabilized, level flight at a constant speed, the power has been adjusted by the pilot so that the thrust is exactly equal to the drag. If the pilot advances the throttle to obtain full power from the engine, the thrust will exceed the drag and the airplane will begin to accelerate. The difference in thrust between the thrust required for level flight and the maximum available from the engine is referred to as "excess thrust". When the airplane finally reaches a speed where the maximum thrust from the engine just balances the drag, the "excess thrust" will be zero, and the airplane will stabilize at its maximum speed.

Notice that this "excess thrust" can be used either to accelerate the airplane to a higher speed (increase the kinetic energy) or to enter a climb at a constant speed (increase the potential energy), or some combination of the two.

There are energy exchange equations which can be used to relate the rate of change of speed (or acceleration) to the rate of change of altitude (or rate of climb). (These equations are introduced later.) In this way, level flight accelerations (accels.) at maximum power can be used to measure the "excess thrust" over the entire speed range of the airplane at one altitude. This "excess thrust" can then be used to calculate the maximum rate of climb capability for an aircraft.

Level flight accelerations and decelerations (accels - decels.) are also used to determine the stability of the airplane with respect to speed. As speed increases a stable airplane will require more nose-down elevator and forward stick force in order to keep the airplane from climbing. The magnitude of this change in trim is a measure of the longitudinal stability of the airplane. At transonic speeds there is a region of speed instability for most supersonic airplanes. The level flight accel.-decel. defines the magnitude and the Mach region where this instability occurs.

For a low performance airplane, such as a Cessna, the stick forces are directly related to the elevator position, since the elevator is connected directly to the stick through a system of cables or pushrods. For a high performance airplane, such as an F-18 fighter, the elevator is moved by hydraulic actuators. The stick forces that the pilot feels are produced artificially by a seperate "artificial feel system". These stick forces may, or may not, be directly related to the position of the elevator. In a modern fly-by-wire flight control system the electronic computer serves to completely separate the commanded elevator position from the pilots stick force, thus hiding any instabilities or trim changes (such as the transonic instability mentioned above) from the pilot. The airplane will always appear to be stable with regard to stick force, even though the elevator position may clearly show an instability.

Accels. and decels. are also performed at constant altitude in turning flight, especially for fighter aircraft. These maneuvers are used to identify the maximum turning capability of an airplane at different altitudes and power settings and are often referred to as windup turns, although they are usually flown at constant "g". These maneuvers are used to define a term called "specific energy" (referred to as "P sub s") for an airplane. This term is very useful in comparing friendly and enemy aircraft. It helps identify which aircraft will have the advantage in a dog-fight, and where within the flight envelope that advantage will be the greatest.

1. Specific Objective of the Test

Determine the acceleration capability (excess thrust) at a particular altitude over the entire speed range of the airplane. Indirectly determine the rate of climb capability at the selected altitude over the entire speed range of the airplane.

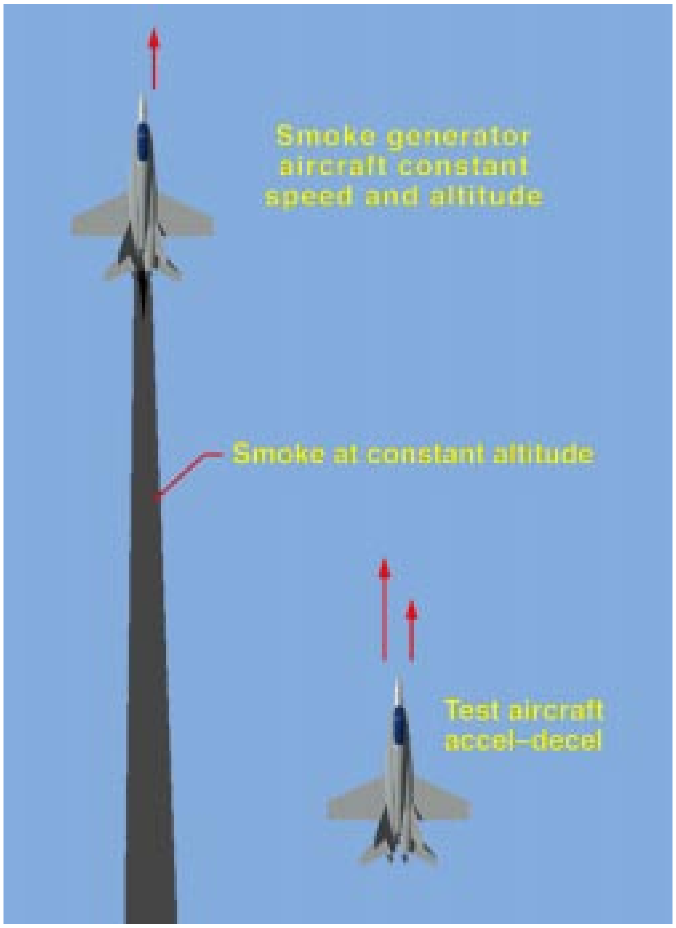
Determine the longitudinal speed stability of the airplane over the entire speed range at a selected altitude.

For turning accels. and decels. (primarily for fighters), determine the thrust-limited turning capability of the airplane at the selected altitude and also the specific energy capability of the aircraft.

2. Critical Flight Conditions

There are several conditions that will influence the data collected during an accel.-decel. The important ones are:

- Altitude - (must be maintained constant.)
- Thrust level - (must be maintained constant.)
- Atmospheric temperature
- Weight
- Center of gravity
- Configuration (flaps and landing gear position)



The need to maintain a precisely constant altitude has influenced the manner in which accels. and decels. are performed. Position error and thrust effects influence the altimeter readings especially during the transonic region, so the altimeter is a poor indicator of precise altitude during an accel. Most accels. are flown along a smoke or condensation trail that has been produced by another airplane flying at constant speed and ahead of the test aircraft.

The limits of stall speed at the low end, and maximum speed at the high end must be observed during the maneuver. For decels. performed in turning flight, the "g" limits must also be observed. Abrupt pitch trim changes and heavy buffet often occur while accelerating or decelerating in the transonic region. The pilot must exercise both caution and skill to maintain the desired g level during the maneuver.

3. Required Instrumentation

The parameters usually measured and recorded during an accel.-decel. are shown inTable (1-1). The engine instruments shown are representative but not complete. The engine instrumentation will be used to correct the acceleration data to standard day pressures and temperatures, rather than to compute actual engine thrust.

A continuous time history of these parameters is needed for the trim point, and throughout the actual maneuver. A sampling rate of at least 10 data samples every second is necessary to accurately record the maneuver, and each data sample must be accurately time correlated with the data samples of the other parameters. That is, we must be able to relate a particular measurement of elevator position with a measurement of speed or Mach number at the same instant in time.

In recent years the use of Inertial Navigation Systems and have been applied quite successfully to the measurement of accelerations and inertial velocities.

4. Starting Trim Point

The flight test engineer will establish a table of altitudes and starting flight conditions where accels.-decels. are desired. This table usually calls for particular trim speed in the center of the speed range of the aircraft. Level flight accels and decels for stability purposes are usually repeated at the same flight condition, but at different values of center of gravity position to identify the "neutral point" of the airplane. A typical sample table of flight conditions for accels-decels is shown in Table (1-2).

A test begins with the initial trim point. The pilot establishes the airplane in level flight at the desired starting flight conditions of speed and altitude. The pilot then uses the trim devices in the airplane's control system to allow the airplane to continue in stable, level flight, but with the pilot's hands and feet off of the controls. A short data recording is taken of this condition, usually referred to as a "trim shot".

5. Description of a Level Flight Accel.-Decel

The chase airplane that is to generate the smoke/condensation trail is established on a constant heading and constant speed. The test aircraft pilot establishes a position behind the smoke-trail aircraft such that he will not pass the airplane during the acceleration. After the trim shot, the pilot reduces the power to idle and decelerates to the minimum desired speed (usually a few knots above stall), while holding the airplane at exactly the same altitude as the smoke trail by using only the pitch control. The pilot will then move the throttle, smoothly but quickly, to full power and allow the airplane to accelerate while maintaining the same altitude as the smoke, again using only the pitch control. When the maximum speed has been reached the pilot will reduce the power to idle and decelerate back to the starting trim speed, continuing to stay at the same altitude as the smoke trail.

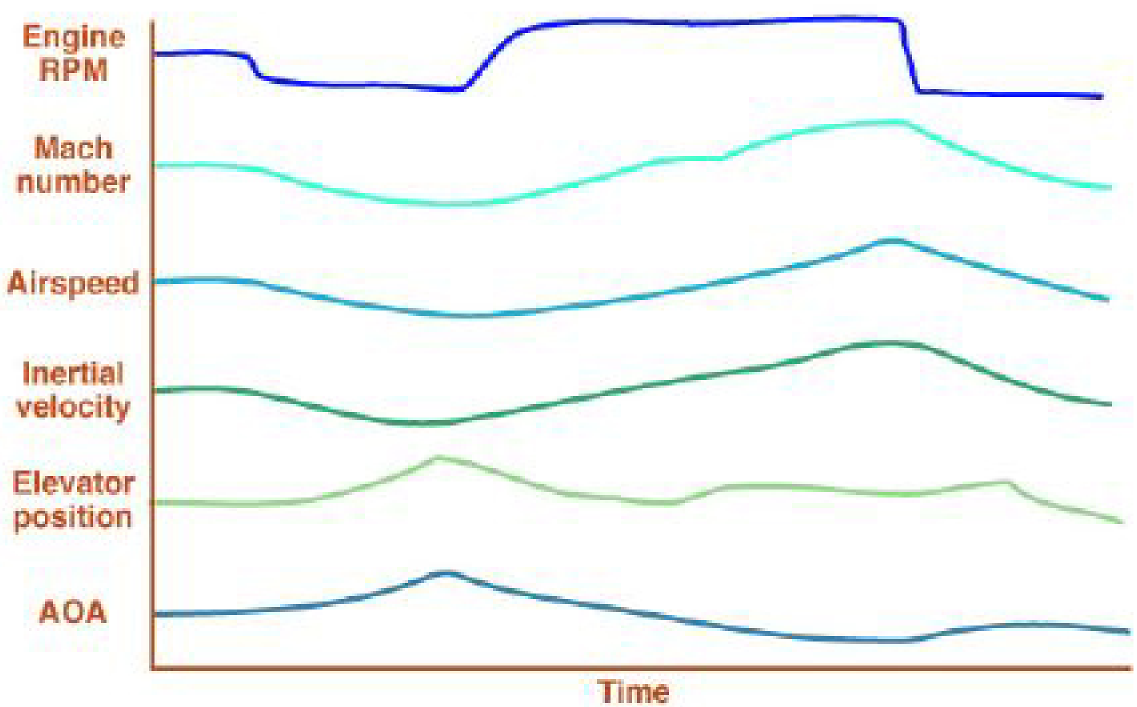
The accel. - decel. should be performed as smoothly as possible. The intent is to maintain th eairplane in steady trimmed flight without any undue oscillations (similar to the piloting technique used in performing pushover-pullups and windup turns).

6. Measures of Success

A successful accel.-decel. will meet the following test criteria:

- All instrumented parameters recorded properly.
- Altitude (after correction for position error) did not change more than 100 feet during the maneuver.
- A smooth application of stick force which stays on one side of the friction band throughout the maneuver.
- Smooth power transitions between idle and max.
- Data successfully crossplots with sawtooth climbs.

A sample accel.-decel time history is shown.



ACCEL-DECEL TIME HISTORY

Several additional decels may be performed at the same altitude in turning flight while holding the g constant at various selected values. For example, starting at maximum speed and with maximum power, decelerating turns may be accomplished while turning and holding 5, 6 and 7 g.

The energy exchange relationship mentioned in the introduction is defined by the following mathematical expression:

$$Fne = \frac{W}{g}\left(\frac{dV}{dt}\right) + \frac{W}{V}\left(\frac{dh}{dt}\right)$$

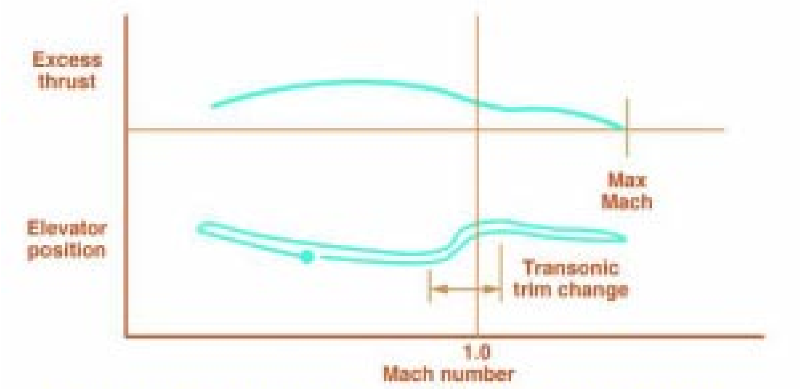
Where F_{ne} = Excess thrust - lbs

W = Weight of the airplane - lbs

g = Acceleration due to gravity 32.16 - ft/sec/sec

V = Velocity - ft/sec

$\left(\frac{dV}{dt}\right)$ = Calculus terminology for acceleration (rate of change of velocity) - ft/sec/sec



EXCESS THRUST & SPEED STABILITY

$\left(\frac{dh}{dt}\right)$ = Calculus terminology for rate of climb (rate ofchange of altitude) - ft/sec

During a level flight acceleration we have forced the second term in the equation to be zero by flying at constant altitude (zero rate of climb). The excess thrust can be computed by measuring the acceleration and weight.

$$Fne = \left(\frac{W}{g}\right) \times \left(\frac{dV}{dt}\right)$$

The equivalent rate of climb can be computed by forcing the first term to zero by assuming a climb at constant velocity (zero acceleration).

$$Fne = \left(\frac{W}{V}\right) \times \left(\frac{dh}{dt}\right)$$

or, rearranging,

$$\left(\frac{dh}{dt}\right) = Fne \div \left(\frac{W}{V}\right)$$

This calculation will produce a value for maximum rate of climb capability (dh/dt) for the flight condition where the weight and acceleration were measured during the accel. The value should be nearly the same as that

Table 1-1
Listing of Instrumentation Parameter

Parameter	Used For
Airspeed	Computer Mach and dyn. pres.
Pressure Altitude	
Outside Air Temperature	
Normal Acceleration	"g" and buffet levels
Elevator Stick Force	Pilot effort req'd to change speed
Elevator Position	Longitudinal stability and transonic trim change
Angle of Attack	Longitudinal stability
Engine RPM	Thrust corrections to standard-day conditions
Engine tailpipe pres. & temp	
Engine inlet pres. & temp.	

Table 1-2
Accel - Decel. Flight Test Conditions

Config	Alt	Trim Speed	Min Speed	Max Mach	cg
Clean	10000	300	190	.95	Fwd and Aft
	20000	300	190	1.2	
	30000	300	190	1.7	
	35000	300	190	1.8	
	45000	300	190	1.8	
Gear, Flaps	5000	180	140	220 knts	